

METHODS OF SAMPLING AND TESTING
MT 210-04
METHOD OF TEST FOR THE MOISTURE-DENSITY
RELATIONS OF SOILS USING A 5.5 LB. (2.5 KG)
RAMMER AND A 12 IN. (305 MM) DROP
(Modified AASHTO T 99)

1 Scope:

- 1.1** These methods of test are intended for determining the relation between the moisture content and density of soils compacted in a mold of a given size with a 5.5 lb. (2.5 kg) rammer dropped from a height of 12 in. (305 mm). Four alternate procedures are provided as follows:
Method A--A 4 in. (101.60 mm) mold: soil material passing a 4.75 mm (No. 4) sieve Sections 3 and 4.
Method B--A 6 in. (152.40 mm) mold: soil material passing a 4.75 mm (No. 4) sieve Sections 5 and 6.
Method C--A 4 in. (101.60 mm) mold: soil material passing a 19.0 mm ($\frac{3}{4}$ in.) sieve Sections 7 and 8.
Method D--A 6 in. (152.40 mm) mold: soil material passing a 19.0 mm ($\frac{3}{4}$ in.) sieve Sections 9 and 10.
- 1.2** The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions of Method A shall govern.

2 Referenced Documents;

2.1 AASHTO:

T 99 Moisture-Density Relations of Soils Using a 5.5 lb. Rammer with a 12 Inch Drop
M 92 Wire Cloth and Sieves for Testing Purposes

MT Manual:

MT-203 Unit Weight of Aggregate
MT-405 Wire Cloth Sieves for Testing Purposes

3 Apparatus:

- 3.1** *Molds*--The molds shall be solid-wall, metal cylinders manufactured with dimensions and capacities shown in 2.1.1 and 2.1.2 below. They shall have a detachable collar assembly approximately 2.375 in. (60 mm) in height, to permit preparation of compacted specimens of soil-water mixtures of the desired height and volume. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base plate made of the same material (Note 1).

Note 1 - Alternate types of molds with capacities as stipulated herein may be used, provided the test results are correlated with those of the solid-wall mold on several soil types and the same moisture-density results are obtained. Records of such correlation shall be maintained and readily available for inspection, when alternate types of molds are used.

- 3.1.1** A 4 in. (101.60 mm) Mold having a capacity of $\frac{1}{30}$ (0.0333) \pm 0.0003 cu. ft. (0.000943 \pm 0.000008 m³) with an internal diameter of 4.000 \pm 0.016 in. (101.6 \pm 0.41 mm) and a height of 4.584 \pm 0.005 in. (116.43 \pm 0.13 mm).
- 3.1.2** A 6 in. (152.40 mm) Mold having a capacity of $\frac{1}{13.33}$ (0.07500 \pm 0.00075 cu. ft. (0.002124 \pm 0.000021 m³) with an internal diameter of 6.000 \pm 0.026 in. (152.4 \pm 0.66 mm) and a height of 4.584 \pm 0.005 in. (116.43 \pm 0.13 mm).

3 Apparatus: (continued)

3.1.3 *Molds Out of Tolerance Due to Use*--A mold that fails to meet manufacturing tolerances after continued service may remain in use provided those tolerances are not exceeded by more than 50 percent; and the volume of the mold, calibrated in accordance with Sec. 6 (Calibration of Measure) of MT-203, for Unit Weight of Aggregate, is used in the calculations.

3.2 **Rammer:**

3.2.1 *Manually Operated*--Metal rammer having a flat circular face of 2.000 ± 0.01 in. (50.80 ± 0.12 mm) diameter, a wear tolerance of 0.01 in. (0.25 mm) and weighing 5.50 ± 0.02 lb, (2.495 ± 0.009 kg). The rammer shall be equipped with a suitable guide-sleeve to control the height of drop to a free fall of 12.00 ± 0.06 (or $1/16$) in. (305 ± 2 mm) above the elevation of the soil. The guide-sleeve shall have at least 4 vent holes, no smaller than $3/8$ in. (9.5 mm) diameter spaced approximately 90 deg. (1.57 rad) apart and approximately $3/4$ in. (19 mm) from each end; and shall provide sufficient clearance so the free fall of the rammer shaft and head is unrestricted.

3.2.2 *Mechanically Operated*--A metal rammer which is equipped with a device to control the height of drop to a free fall of 12.00 ± 0.06 (or $1/16$) in. (305 ± 2 mm) above the elevation of the soil and uniformly distributes such drops to the soil surface (Note 2). The rammer shall have a flat circular face 2.000 ± 0.01 in. (50.80 ± 0.127 mm) diameter, a wear tolerance of 0.01 in. (0.25 mm) and a manufactured mass of 5.50 ± 0.02 lb. (2.495 ± 0.009 kg). The mechanical rammer shall be calibrated by ASTM Method D 2168 to give the same moisture-density results as with a manually operated rammer.

Note 2 - It may be impractical to adjust the mechanical apparatus so the free fall is 12 in. (305 mm) each time the rammer is dropped, as with the manually operated rammer. To make the adjustment of free fall, the portion of loose soil to receive the initial blow should be slightly compressed with the rammer to establish the point of impact from which the 12 in. (305 mm) drop is determined. Subsequent blows on the layer of soil being compacted may all be applied by dropping the rammer from a height of 12 in.

3.2.3 *Rammer Face*--The circular face rammer shall be used but a sector face may be used as an alternative provided the report shall indicate type of face used other than the 2 in. (50.8 mm) circular face and it shall have an area equal to that of the circular face rammer.

3.3 *Sample Extruder*--A jack, lever, frame, or other device adopted for the purpose of extruding compacted specimens from the mold.

3.4 *Balances and Scales*--A balance or scale of at least 25 lb. capacity having a sensitivity and readability to 0.01 lb., or a balance or scale having a capacity of approximately 11.5 kg and a sensitivity and readability to 5 grams. (Note 3) Also, a balance of at least 1 kg capacity with a sensitivity and readability to 0.1 g.

Note 3 - The capacity of the metric balance or scale should be approximately 11.5 kg when used to weigh the 6 in. (152 mm) mold and compacted, moist soil; however, when the 4-in. (102 mm) mold is used, a balance or scale of lesser capacity than the 11.5 kg may be used, if the sensitivity and readability is 5 g.

3.5 *Drying Oven*--A thermostatically controlled drying oven capable of maintaining a temperature of $110 \pm 5^\circ$ C ($230 \pm 9^\circ$ F) for drying moisture samples.

3.6 *Straightedge*--A hardened-steel straightedge at least 10 in. (250 mm) in length. It shall have one beveled edge, and at least one longitudinal surface (used for final trimming) shall be plane within 0.01 in. per 10 in. (0.1 percent) (0.250 mm per 250 mm) of length within the portion used for trimming the soil (Note 4).

3 Apparatus: (continued)

Note 4 - The beveled edge may be used for final trimming if the edge is true within a tolerance of 0.001 in. per 10 in. (0.1 percent) (0.250 mm per 250 mm) of length; however, with continued use, the cutting edge may become excessively worn and not suitable for trimming the soil to the level of the mold. The straightedge should not be so flexible that trimming the soil with the cutting edge will cause a concave soil surface.

3.7 Sieves—2-in. (50 mm), ¾-in. (19.0 mm), and No. 4 (4.75 mm) sieves conforming to the requirements of MT-405 (AASHTO M 92), Sieves for Testing Purposes.

3.8 Mixing Tools--Miscellaneous tools such as mixing pan, spoon trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

3.9 Containers--Suitable containers made of material resistant to corrosion and not subject to change in weight or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.

METHOD A**4 Sample:**

4.1 If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of drying apparatus such that the temperature of the sample does not exceed 60° C (140° F). Then thoroughly break up the aggregations in such a manner to avoid reducing the natural size of individual particles.

4.2 Sieve an adequate quantity of the representative pulverized soil over the No. 4 (4.75 mm) sieve. Discard the coarse material, if any, retained on the No. 4 (4.75 mm) sieve.

4.3 Select a representative sample, with a mass of approximately 7 lb. (3 kg) or more, of the soil prepared as described in Sections 4.1 and 4.2.

5 Procedure:

5.1 Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately four percentage points below optimum moisture content.

5.2 Form a specimen by compacting the prepared soil in the 4 in. (101.60 mm) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 5 in. (125 mm). Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a loose or fluffy state, using either the manual compaction rammer or a similar device having a face diameter of approximately 2 inches (50 mm). Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 12 in. (305 mm) above the elevation of the soil when a sleeve-type rammer is used, or from 12 in. (305 mm) above the approximate elevation of compacted soil when a stationary mounted type of rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid and stable foundation (Note 5).

Note 5 - Each of the following has been found to be a satisfactory base on which to rest the mold during compaction of the soil: A block of concrete, weighing not less than 200 lb. (90 kg), supported by a relatively stable foundation; a sound concrete floor; and for field application, such surfaces as found in concrete box culverts, bridges, and pavements.

5.2.1 Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge, and weigh the mold and moist soil in pounds, to

the

5 Procedure: (continued)

nearest 0.01 lb., or weigh in kilograms to the nearest 5 grams. For molds conforming to tolerances given in Section 3.1.1 and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 30, and record the result as the wet density, W_1 , in pounds per cubic foot, of compacted soil. For molds conforming to tolerances given in Section 3.1.1 and masses recorded in kilograms, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 1059.43, and record the result as the wet density, W_1 , in kilograms per cubic meter, of compacted soil. For used molds out of tolerance by not more than 50 percent (3.1.3), use the factor for the molds as determined in accordance with Section 6 (Calibration of Measure), MT-203.

- 5.3** Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces, weigh immediately, and dry in an oven at $110 \pm 5^\circ\text{C}$ ($230 \pm 9^\circ\text{F}$) for at least 12 hours, or to a constant mass to determine the moisture content. The moisture sample shall weigh not less than 100 g.
- 5.4** Thoroughly break up the remaining portion of the molded specimen until it will pass a No. 4 (4.75 mm) sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amount to increase the moisture content of the soil by one or two percentage points, and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet unit mass. W_1 , per cubic foot or cubic meter of the compacted soil (Note 6).

Note 6 - This procedure has been found satisfactory in most cases. However, in instances where the soil material is fragile in character and will reduce significantly in grain size due to repeated compaction, and in cases where the soil is a heavy-textured clayey material into which it is difficult to incorporate water, a separate and new sample shall be used in each compaction test. In these cases, separate samples shall be thoroughly mixed with amounts of water sufficient to cause the moisture contents of the samples to vary by approximately two percentage points. The moisture points selected shall bracket the optimum moisture content, thus providing samples which when compacted will increase in mass to the maximum density and then decrease in mass. The samples of soil-water mixtures shall be placed in covered containers and allowed to stand for not less than 12 hours before making the moisture-density test.

- 5.4.1** In instances where the soil material is fragile in character and will be reduced significantly in grain size by repeated compaction, a separate and new sample shall be used in each compaction test.

METHOD B

6 Sample:

- 6.1** Select the representative sample in accordance with 4.3, except that it shall have a mass of approximately 16 lb. (7 kg).

7 Procedure:

- 7.1** Follow the same procedure as described for Method A in Section 4, except for the following: Form a specimen by compacting the prepared soil in the 6-in. (152.4 mm) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 5 in. (125 mm), each layer being compacted by 56 uniformly distributed blows from the rammer. For molds conforming to tolerances in 3.1.2, and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 13.3, and record the result as the wet density, W_1 , in lb. ft.³, of the compacted soil. For molds conforming to tolerances given in 3.1.2 and masses recorded in kilograms, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 471, and record the results as the wet density, W_1 , in kg/m³, of compacted soil. For used molds out of tolerance by not more than 50 percent (3.1.3),

use the factor for the mold as determined in accordance with Section 6 (Calibration of Measure), MT-203.

METHOD C

8 Sample:

- 8.1** If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of drying apparatus such that the temperature does not exceed 60° C (140° F). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.
- 8.2** Sieve an adequate quantity of the representative pulverized soil over the 3/4 in. (19.0 mm) sieve. Discard the coarse material if any, retained on the 3/4 in. (19.0 mm) sieve (Note 7).

Note 7 - If it is advisable to maintain the same percentage of coarse material (passing a 50 mm sieve and retained on a 4.75 mm sieve) in the moisture-density sample as in the original field sample, the material retained on the 19.0 mm sieve shall be replaced as follows: Sieve an adequate quantity of the representative pulverized soil over the 50 mm and 19.0 mm sieve. Weigh the material passing the 50 mm sieve and retained on the 19.0 mm sieve and replace it with an equal mass of material passing the 19.0 mm sieve and retained on the 4.75 mm sieve. Take the material for replacement from the remaining portion of the sample.

- 8.3** Select a representative sample, having a mass of approximately 12 lb. (5 kg) or more, of the soil prepared as described in 4.1 and 4.2.

9 Procedure:

- 9.1** Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately 4 percentage points below optimum moisture content.
- 9.2** Form a specimen by compacting the prepared soil in the 4 in. (102.60 mm) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 5 in. (125 mm). Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a loose or fluffy state, using either the manual compaction rammer or a similar device having a face diameter of approximately 2 inches (50 mm). Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 12 in. (305 mm) above the elevation of the soil when a sleeve-type rammer is used, or from 12 in. (305 mm) above the approximate elevation of each finally compacted layer when a stationary mounted type rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid and stable foundation (Note 5).
- 9.2.1** Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge. Holes developed in the surface by removal of coarse material shall be patched with smaller size material. Weigh the mold and moist soil in pounds to the nearest 0.01 lb.; or weigh in kilograms to the nearest 5 grams. For molds conforming to tolerances given in Section 3.1.1, and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 30, and record the result as the wet density, W_1 , in lb./ft.³, of compacted soil. For molds conforming to tolerances given in Section 3.1.1 and masses recorded in kilograms, multiply the mass of the compacted specimen and mold, minus the mass of the mold, by 1060, and record the result as wet density, W_1 , in kg/m³, of compacted soil. For used molds out of tolerance by not more than 50 percent (3.1.3), use the factor for the mold as determined in accordance with Section 6 (Calibration of Measure), MT-203.

9 Procedure: (continued)

- 9.3** Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces, weigh immediately, and dry in an oven at $110 \pm 5^\circ \text{C}$ ($230 \pm 9^\circ \text{F}$) for at least 12 hours, or to constant mass, to determine the moisture content. The moisture content sample shall weigh not less than 500 g.
- 9.4** Thoroughly break up the remainder of the material until it will pass a 3/4 in. (19.0 mm) sieve and 90 percent of the soil aggregations will pass a 3/4 in. (4.75 mm) sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amounts to increase the moisture content of the soil sample by one or two percentage points, and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet mass, W_1 , per cubic foot or cubic meter of compacted soil (Note 6).

METHOD D**10 Sample:**

- 10.1** Select the representative sample in accordance with 7.3 except that it shall have a mass of approximately 25 lb. (11 kg).

11 Procedure:

- 11.1** Follow the same procedure as described for Method C in Section 8 except for the following. Form a specimen by compacting the prepared soil in the 6 in. (152.4 mm) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 5 in. (125 mm), each layer being compacted by 56 uniformly distributed blows from the rammer. For molds conforming to tolerances given in 3.1.2 and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 13.33, and record the results as the wet unit mass, W_1 , in lb/ft³, of the compacted soil. For molds conforming to tolerances given in 3.1.2 and masses recorded in kilograms, multiply the mass of the compacted specimen and mold, minus the mass of the mold, by 471, and record the result as the wet unit mass, W_1 , in kg/m³ of compacted soil. For used molds out of tolerance by not more than 50 percent (3.1.3), use the factor for the mold as determined in accordance with Section 6 (Calibration of Measure) MT-203.

CALCULATIONS AND REPORT**12 Calculations:**

- 12.1** Calculate the moisture content and the dry unit mass of the soil as compacted for each trial, as follows:

$$w = \frac{A - B}{B - C} \times 100$$

and

$$W = \frac{W_1}{w + 100} \times 100$$

12 Calculations: (continued)

where:

- w = percentage of moisture in the specimen, based on oven dry mass of soil.
- A = mass of container and wet soil.
- B = mass of container and dry soil.
- C = mass of container.
- W = dry mass, in pounds per cubic foot of compacted soil, or kilograms per cubic meter of compacted soil, and
- W_1 = wet mass, in pounds, per cubic foot of compacted soil or kilograms per cubic meter of compacted soil.

13 Moisture-Density Relationship:

- 13.1** The calculation in 12.1 shall be made to determine the moisture content and corresponding oven-dry unit mass (density) in pounds per cubic foot or kilograms per cubic meter of the compacted samples. The oven-dry densities (unit weight) of the soil shall be plotted as ordinates and the corresponding moisture content as abscissas.
- 13.2** *Optimum Moisture Content*--When the densities and corresponding moisture contents for the soil have been determined and plotted as indicated in 13.1, it will be found that by connecting the plotted points with a smooth line, a curve is produced. The moisture content corresponding to the peak of the curve shall be termed the "optimum moisture-content" of the soil under the above compaction.
- 13.1** The calculations in 12.1 shall be made to determine the moisture content and corresponding oven-dry unit mass (density) in pounds per cubic foot or kilograms per cubic meter of the compacted samples. The oven-dry densities (unit weight) of the soil shall be plotted as ordinates and the corresponding moisture content as abscissas.
- 13.2** *Optimum Moisture Content*--When the densities and corresponding moisture contents for the soil have been determined and plotted as indicated in 13.1, it will be found that by connecting the plotted points with a smooth line, a curve is produced. The moisture content corresponding to the peak of the curve shall be termed the "optimum moisture-content" of the soil under the above compaction.
- 13.3** *Maximum Density*--The oven-dry density in pounds per cubic foot or kilograms per cubic meter of the soil at optimum moisture content shall be termed "maximum density" under the above compaction.

14 Report:

- 14.1** The report shall include the following:
 - 14.1.1** The method used (Method A, B, C, or D),
 - 14.1.2** The optimum moisture content, as a percentage, to the nearest whole number,
 - 14.1.3** The maximum density in lbs. per cu. ft., to the nearest 0.1 lb/ft³ or in kilograms per cubic meter, the nearest 1 kg.,
 - 14.1.4** In Methods C and D indicate if the material retained on the 19.0 mm sieve was removed or replaced.,

14.1.5 Type of face if other than 2 in. (50.8 mm) circular.